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(71) Applicant: Japan Casting & Forging Corporation
6-2, 2-chome Ohte-machi
Chiyoda-ku Tokyo(JP)

(72) Inventor: Saeki, Keiji
2-1, Takami 1-chome Yahatahigashi-ku
Kitakyushu City Fukuoka Prefecture(JP)

(72) Inventor: Hirose, Yutaka
4-8, Hinosato 6-chome
Munakata City Fukuoka Prefecture(JP)

(72) Inventor: Kusano, Kazuhiro
1-2-705, Midorigaoka Ashiyacho
Onga-gun Fukuoka Prefecture(JP)

(72) Inventor: Tashiro, Yasunori
13-1, Kasugadai 5-chome, Yahatanishi-ku
Kitakyushu City Fukuoka Prefecture(JP)

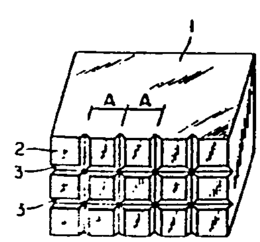
(72) Inventor: Takebayashi, Kazunari
1-1-804, Midorigaoka Ashiyacho
Onga-gun Fukuoka Prefecture(JP)

(74) Representative: Vossius Vossius Tauchner Heunemann Rauh
Siebertstrasse 4 P.O. Box 86 07 67
D-8000 München 86(DE)

## (54) Method for manufacturing steel castings.

(57) Method for manufacturing steel castings characterized by a novel means for preventing cracks from occurring on the surface skin of said cast steel in which the surface (2) of a direct chill (1) applied to a casting mould is provided with a series of protuberances and depressions which divides or disperses the shrink stress on the surface skin of said cast steel.

FIG. 2




EP 0 094 688 A1

Croydon Printing Company Ltd.

Our ref.: S 448 EP
Case: JCF

May 18, 1983

Japan Casting & Forging Corporation
Tokyo, Japan

METHOD FOR MANUFACTURING STEEL CASTINGS

The present invention relates to an improvement concerning a direct chill used on part or all of a mould for the steel casting.

Description of the prior art

Steel castings have advantages over rollings and forgings in that there is less restriction on the shape of the product obtained. On the other hand, however, they entail the drawback that, in the case of using a sand mould, internal defects occur in the casting. The occurrence of these defects is inherently related to the solidification of the steel during the casting and is particularly pronounced in the case of large and intricately shaped castings.

Hitherto, as a remedy for preventing the above defects by controlling the solidification behaviour of the cast steel, chills, i.e. blocks of iron or steel, have been applied at specific locations on the surface of the mould so as to promote cooling and solidification of the casting at these portions, whereby the internal quality of the casting has been effectively improved.

Experience shows, however, that cracking of casting surface may to occur at portions of the casting where a chill is applied and that this tendency increases with increasing size of the casting and increasing area

of the chill. As reasons for the occurrence of such cracking, the following can be mentioned: A first reason is that when a chill is applied to the cast steel, the surface of the casting is chilled more rapidly at the portion of the chill than at the portion of the sand mould, giving rise to a rapidly occurring shrink stress associated with the solidification. A second reason is that the chill does not at all follow the deformation accompanied with a solidification shrink of the casting; and, conversely, the chill exhibits a behaviour opposite to the solidification shrink of the casting due to the expansion of the chill resulting from the temperature rise so that it promotes the occurrence of a surface cracking.

As a method for preventing cracking of the surface skin of the casting, it is known to use internal chills buried in the sand mould as illustrated in Fig. 1. In this figure, the numeral 20 denotes a sand mould, 21 chills, 22 sand, 24 sand layer, and 23 a roll to be cast. This method, however, has the disadvantage that the cooling effect of the chill is reduced by the sand layer 24 in front of the chill 21.

Hitherto, there has been no satisfactory method for preventing surface cracking of a casting produced with the use of direct chills. Therefore, the cracks occurring in the surface skin of the casting must be removed by scarfing and repaired by welding. This entails

a considerable increase in processing steps as well as manufacturing costs, and consequently there was a longfelt need for a satisfactory remedy.

As a technique for avoiding cracks in the casting surface, it is known to use a fluted or corrugated mould for a steel ingot to be rolled or forged. Macroscopically viewed, these ingots have simple square, rectangular or circular sectional shapes. Since the cracks caused by the solidification of the ingot occur on the outer surface thereof mostly in the height direction, the ridges and valleys are formed in one direction parallel to the axis of the ingot.

In consideration of the shrinking characteristics of the casting, the form of fluting or corrugation is generally designed in a complicated curve. This method is considered to be capable of almost totally preventing longitudinal cracking of steel ingot. In cast steel, however, cracking occurs in spite of the fact that the area of the casting surface to which the chills are applied is far smaller than the area of a steel ingot mould which requires fluting or corrugation. This is because the shape of the castings is far more complicated than that of steel ingot mould, and also because stresses occur in many directions on the surface of the casting to which the chill is applied. The vectorial stress is built up to give a uni-directional stress from random-directional stress. When the composed stress on the surface

of castings to which the chill is applied exceeds the ultimate strength of the castings, a crack occurs inevitably on the surface of the castings in direction perpendicular to that of the composed stress . This means that it is necessary to take into consideration the stresses occurring in many directions in the surface of the steel casting at the points where chills are applied.

In U.S. Patent No.4,250,950, it is proposed that a mould be provided with a roughened surface so that the melt comes into contact only with the peaks of the projections on the mould surface and an air gap is formed between the melt and the valleys on the surface of mould in order to regulate the heat transfer from the melt to the mould. However, this U.S. Patent discloses no method for improving the internal quality and properties of a casting produced with the application of chills.

## SUMMARY OF THE INVENTION

It is a prime object of the present invention to provide a method for producing steel castings with improved internal quality and properties.

It is another object of the invention to provide a method for producing steel castings wherein the shrink stress on the surface of the casting is divided.

It is still another object of the invention to provide an improved method for producing steel castings

wherein a direct chill is used in order to prevent the occurrence of cracks on the surface of the casting.

BRIEF DESCRIPTION OF THE DRAWINGS

Other and further objects of the invention will become apparent to those skilled in the art from the following detailed description of the invention with reference to the accompanying drawings which illustrate preferred embodiments of the invention.

Fig. 1 is a side view of a prior art in which a chill is used;

Fig. 2 is a view showing the surface of a chill provided with a groove lattice;

Fig. 3 is a view of the sectional shape of a groove;

Fig. 4 is a graph showing the crack prevention effectiveness of a large planar chill provided with the groove lattice;

Figs. 5(a),(b),(c) and (d) are views showing continuous triangular and hexagonal groove and pit patterns;

Fig. 6 is a graph showing a comparison between the amount of repair work required by castings produced by the method of this invention and by the method of prior art;

Figs. 7(a) and (b) are views showing a truncated cone-shaped pit and a truncated sphere-shaped pit;

Fig. 8 is an explanatory view of an embodiment of the invention;

Fig. 9 is an explanatory view of another embodiment

of the invention; and

Fig. 10 is a perspective view of the chill shown in Fig. 9.

DETAILED DESCRIPTION OF THE INVENTION

This invention was accomplished on the basis of an extensive analytical study on the shrink stress in the surface skin of cast steel. It is known to apply a direct chill (referred to as a "chill" hereinafter) to part or all of the surface of a steel casting within a mould. The gist of the present invention resides in providing an improved chill having surface irregularities, i.e. projection and depression, which function to divide the shrink stress in the surface of the casting.

It is generally known that cracks appear at points of a casting where the stress exceeds the ultimate strength of the casting surface. Thus, in order to prevent cracks, it is necessary to either increase the strength of the casting or decrease the stress. The strength of cast steel depends on the required properties of the product to be cast, and it is impossible to regulate the strength only on the surface thereof. As the stress in the surface skin of the casting is a tensile stress, it can be presumed to be caused by the solidification shrink. The sum total of stress depends on the shape and area of the casting surface and cannot be increased or decreased at will.

In the case of a small chill, the amount of tensile

stress arising in the surface skin of the casting where the chill is applied is little enough to produce a crack. In the course of the research, the inventors found that when using a single chill having a surface measuring not more than 200 mm both in width and length (referred to as a "small chill" hereinafter), these is less danger of cracking of the surface skin of the casting.

On the contrary, however, use of a plurality of small chills which have a surface width and/or length exceeding 200 mm in a bundle and/or single block (referred to as a "large chill" hereinafter), tends to increase radically in the susceptibility to cracking on the surface skin of the casting.

An intention to decrease the crack-inducing stress by reducing the thickness and/or area of the chill applied to the casting surface would be inconsistent with the fundamental aim to improve the internal properties of the casting through the cooling effect of the chill. For preventing internal defects it is necessary to use a large chill having sufficient thickness and area and this large chill must prevent crack formation on the surface of castings.

Based on the above-mentioned study in connection with the cracking of a casting surface to which a chill is applied, the inventors have succeeded in preventing cracks from occurring in the surface skin of a casting by a novel process wherein the stresses acting on the

casting surface in many directions are so dispersed in many directions that the absolute value of the composite stress is maintained at a value less than that of the ultimate strength of the cast steel. More specifically, they have conceived the idea of providing the surface of a chill with which the casting surface comes into contact with a consecutive pattern consisting of surface irregularities (i.e. projections and depressions) extending not in one direction but in many directions.

Now, the present invention will be described hereinbelow in detail with reference to the drawings.

Fig. 2 shows an embodiment of a large planar chill in which the fundamental idea of the present invention is illustrated. As shown in Fig. 2, the surface 2 of the chill 1 with which the casting comes into contact is provided with orthogonally intersecting groove 3 which forms a lattice for coping with stress acting in two directions: lateral and longitudinal, or vertical and horizontal. Thus, the surface skin 4 of the casting, which is a large field of solidification shrink stress, is divided into a number of small fields of stress limited by the surrounding grooves. With this arrangement, since the absolute value of the stress in each small field of stress is held well under the ultimate strength limit of casting, no cracking occurs in the surface skin.

Since the function of the grooves is to divide the surface skin of casting into small fields of stress, they are of no practical use if they are too shallow. The depth F of the grooves depends on the casting conditions, and it has been confirmed by experiments that a groove depth F of more than about 5 mm is sufficient for the ordinary casting process. Moreover, if the angle between the side wall 5 of the groove 3 and the surface 2 of the chill is in the vicinity of 90 degrees, the restraint of the casting surface 4 becomes too strong due to the groove 3 and a concentrated point of shrink stress is easily formed in the surface skin 4 around the groove 3. Accordingly, it has been found that this angle should ordinarily be greater than 120 degrees, and preferably about 135 degrees.

Furthermore, if the intersection between the side wall 5 of the groove 3 and the chill surface 2 should form a distinct brink edge having a sharp angle, then the brink edge is transcribed onto the surface skin 4, with the result that the corner 6 becomes a concentrated point of stress on the surface skin 4. As this would promote, not prevent, cracking, the corner 6 should be made round and smooth. In order to realize effective alleviation of stress due to shrink of surface skin, it has been confirmed that the radius of curvature R of the corner should preferably be greater than depth F of the groove 3.

In addition to the above, the groove 3 is formed so that the surface area of the cast steel is increased and the groove 3 also provides a shrink allowance to alleviate the surface shrink stress caused by solidification and reduction of temperature. The angle of the side wall of the groove as well as the roundness at the brink edge formed by the intersection of the groove and the chill surface function to facilitate smooth shrinking of the surface skin.

The primary factors which determine the shrink allowance of the surface skin 4 are the depth F and the groove interval A. And a secondary factor is the curvature R of the groove edge which has a large effect on the stress concentration but only a small effect toward increasing the casting surface area to provide a shrink allowance. Experiments using a hollow cylinder casting showed that the following conditions are required:

| | (groove interval/ groove depth) | (remaining chill surface after the grooves are cut) |
|---|---|---|
| (1) External chill | less than 20 | less than 80% |
| (2) Internal chill | less than 12 | less than 70% |
| (3) Bottom chill | less than 12 | less than 70% |

The external chill is subject to less restriction than the other chills because an air gap is formed by the solidification shrink of the cast steel. It is not always necessary to meet both of the above two conditions

but it is preferable to do so.

Fig. 4 shows the effectiveness in preventing cracks in the surface skin of a casting obtained when a large planar chill provided with a groove lattice in accordance with the present invention was actually used to produce a cast product.

In Fig. 4 the hatched areas indicate the amount of repair work necessitated by cracks. Thus if the method of this invention is followed faithfully a remarkable reduction in the cracking of the surface skin to which the chill is applied is observed.

Moreover, application of the chill provided with the groove lattice to an outside pattern of cylindrical shape was found to give the same result as those obtained with the use of the large planar chill. In the case of applying a chill of a cylindrical core type or a spherical chill, however, it has been found that it is not possible to satisfactory by prevent cracking in the surface skin of the casting even if a chill having an orthogonal groove lattice is used. This is because of the complicated behaviour of the stress acting on the surface skin.

In searching a way to overcome this problem, the inventors conceived the idea of distributing the stress occurring in the surface skin 4 into, for instance, three or six directions. This can be realized by providing the surface of the chill with grooves 3 in a continuous

triangular pattern (Fig. 5(a)) or a continuous hexagon pattern (Fig. 5(b)) or with conic or truncated cone-shaped pits (Fig. 7(a)) or spherical truncated sphere-shaped pits (Fig. 7(b)) at the apexes A, B and C of triangles or at the apexes A, B, C, D, E and F of hexagons.

The foregoing comments regarding the groove lattice of Fig. 2 and Fig. 3 also apply to the roundness at each edge of these triangularly and hexagonally arranged grooves 3 and pits 8.

The important point is to disperse the stress. In some cases a pentagonal or octagonal pattern can also be used.

The chill sometimes sticks to the cast steel by fusion.

This fusion sticking can be prevented by coating the chill surface with a mold wash. However, this amounts to coating the chill surface with a material of low thermal conductivity and reduces the cooling effect on the casting as well as the effect toward improving the interior quality of the casting by means of the chill.

Accordingly, the thickness of the mold wash in required to be as thin as possible. In accordance with the inventors' study, it should not exceed 5 mm.

Insofar as this limit is observed, the chill provided with the novel means for

crack prevention in accordance with the present invention can be coated with a mould wash.

Embodiments of the invention are described hereinbelow.

Example 1

An example in which the chill of the invention is applied to the thick portion of a cast steel having thin and thick portions is described below. Fig. 8 illustrates the chill 11-1 and 11-2 in contact with a finished product 13, a sand 12, and surface of casted steel melt L immediately after pouring into a casting mould.

Product: Bowl type steel casting with a support lug.

| | |
|---|---|
| Maximum thickness of bowl shape portion | 200 mm |
| Weight of poured steel | 120 tons |
| Inner radius of hemisphere | 1550 mm |
| Size of support lug: | |
| longitudinal length | 400 mm |
| depth of bottom | 400 mm |
| top | 100 mm |
| width | 500 mm |

Application of chill:

| | |
|---|---|
| Scope of application: | Side and bottom of support lug |
| Thickness of chill : | 100 mm |
| Area of chill : | 400 x 500 mm |
| Surface pattern of chill: | Orthogonally intersecting grooves |

Groove shape:

| | |
|---|---|
| groove depth | 10 mm |
| groove width | 20 mm |
| groove edge curvature | 10 mm |
| groove interval | 100 mm |

Steel Quality: SC49 (0.25%C, 0.40%Si, 0.95%Mn, and the balance Fe)

The casting produced according to this Example 1 had no cracks at all in the surface skin and the excellent internal quality of the support lug was also confirmed by radiographic examination.

Example 2

A cast steel was manufactured by the method of the invention in which a chill provided with conic pits on the apexes of a continuous triangular pattern (one of the embodiments of the invention) was applied to the whole surface of a core. A cast steel product 13 was manufactured using a sand mould 12 provided with a chill 11 as shown in Fig. 9. In this figure L denotes the surface of the cast steel melt immediately to be poured. Fig. 10 is a perspective view of the surface of the chill 11.

Product: Arc-like cast steel with ribs (thickness of the product 250 mm; poured weight 21.6 tons)

Steel quality: SC49 (0.25%C, 0.40%Si, 0.94%Mn, balance Fe)

Shape of casting: Total width 1935 mm, cylindrical surface

width 1635 mm, rib thickness 150 mm, total height of product 1800 mm, inside radius of cylinder 1550 mm.

Application of chill:

| | | |
|---|---|---|
| Scope of application | : | Whole inside surface skin of cylindrical product |
| Chill thickness | : | 500 mm |
| Surface pattern of chill | : | Conic pits at apexes of continuous triangular pattern |
| Pit shape | : | 110 mm in diameter, 45 mm deep |

Interval between pit centers: 183 mm

Carrying out the method of the present invention clearly showed that dispersion of the stress on the surface skin of the casting into three or six directions is more effective than that of stress dispersion into two directions in the case of a chill for the cylindrical core or the spherical core.

Scarfing and welding repair work due to surface cracks of castings was notably decreased and became substantially zero. The hatched areas in Fig. 6 show the amount of repair work necessitated by surface cracks of the castings when using direct chills of the prior art to chills with hemispherical cones.

Example 3

In this example a mould wash was used.

Product: Heavy cast steel plate (200 mm thick, 1800 mm wide and 2500 mm long)

Steel quality: SC46 (0.2%C, 0.40%Si, 0.80%Mn, balance Fe)

A single unit planar chill was applied to the bottom of the casting.

Chill: 300 mm thick, 1800 mm wide, and 2500 mm long

Means for preventing cracks: Orthogonally intersecting grooves: groove depth 25 mm, groove width 50 mm, groove interval 250 mm.

Under the above conditions, a mould wash was used as shown in Table 1.

Table 1

| Mold wash | Mold wash thickness | Cracks | Thickness of sound layer |
|---|---|---|---|
| Yes | 3 mm | No | 200 mm |
| No | - | No | 200 mm |

As clearly indicated in Table 1, use of the mould wash did not cause cracking or any change in the thickness of the sound layer in so far as the layer of the mould wash is thin enough.

As fully described in the foregoing, a preferred embodiment of a chill of the present invention is provided with a groove lattice,

a continuous triangular or hexagonal groove pattern or polygonal pattern constituted of conic, truncated cone-shaped, spherical or truncated sphere-shaped pits provided at the apexes of the polygons. The chill of present invention can be applied to an extensive area of castings and gives good results as regards the improvement of internal qualities without any crack formation on the surface skin of castings. As a result with the present invention it is possible to greatly reduce the amount of repair of the surface skin of the casting and thus to save manufacturing cost, and accelerate the delivery of casting products.

In addition to the above, the present invention can be applied to a casting process using an outer mould. It is understood that such an application is within the scope of the present invention.

WE CLAIM:

1. Method for manufacturing steel casting with direct chill, characterized in that the direct chill is provided with surface irregularities which divide the shrink stress occurring in the surface skin of the cast steel.

2. The method as claimed in claim 1 characterized in that the direct chill having a surface measuring 200 mm or more in length and 200 mm or more in width is provided with surface irregularities in the form of a lattice constituted of orthogonally or triangularly intersecting and/or hexagonally ditched grooves, the side walls of each said groove forming an angle with the surface of said chill which is greater than 90°, preferably more than 120°, but less than 180°.

3. The method as claimed in claim 2 characterized in that the corners formed by the intersection of each said side wall with said surface of said chill are rounded.

4. The method as claimed in claim 2 or 3 characterized in that the depth of said grooves is more than 5 mm.

5. The method as claimed in claims 3 or 4 in which the radius of rounded corners formed by the intersection of said side walls and said chill surface is equal to or

greater than the depth of said grooves.

6. The method as claimed in any of claims 2 to 5 in which the intervals between said grooves are not more than 20 times the groove depth and the remaining surfaces of said chill after said grooves are cut are not more than 80% of the whole surface of said chill, respectively, in the case of an external side chill, and are not more than 12 times the groove depth and not more than 70% of the whole surface of said chill, respectively in the case of an internal side chill and a bottom chill.

7. The method as claimed in any of claims 1 to 6 in which the surface irregularities of the chill is in the form of conic or truncated cone-shaped pits formed at the apexes of consecutive patterns of triangles or hexagons.

8. The method as claimed in any of claims 1 to 7 in which the surface irregularities of the chill is in the form of spherical or truncated sphere-shaped pits formed at the apexes of triangles or hexagons.

9. The method as claimed in any of claims 1 to 8 in which the surface of said chill is coated with a mould wash to a thickness of not more than 5 mm.

FIG. 1

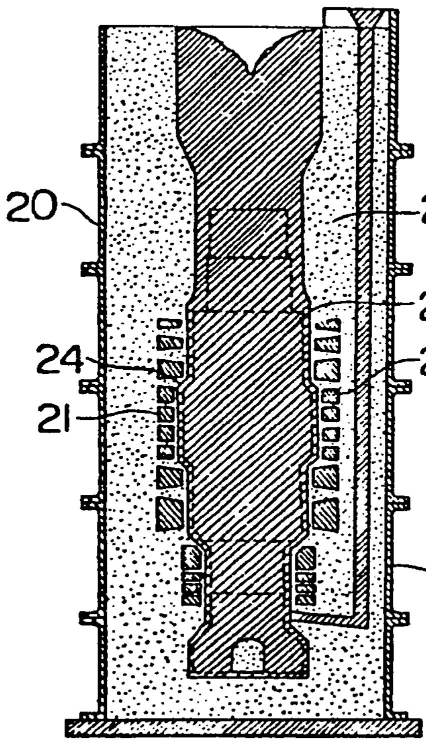



FIG. 2

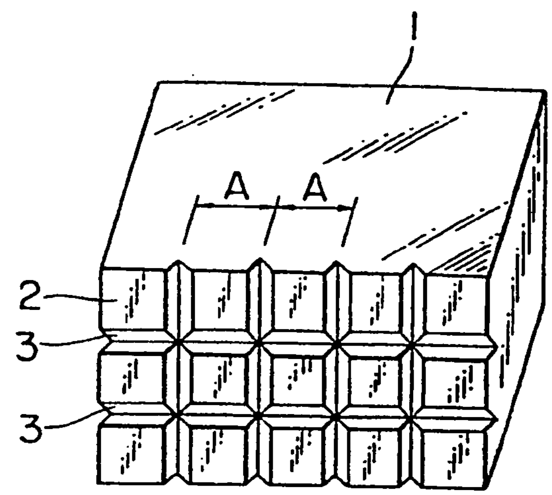



FIG. 3

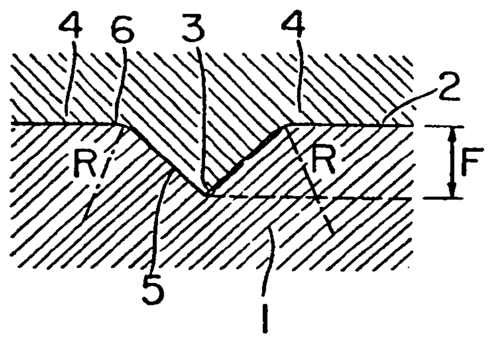
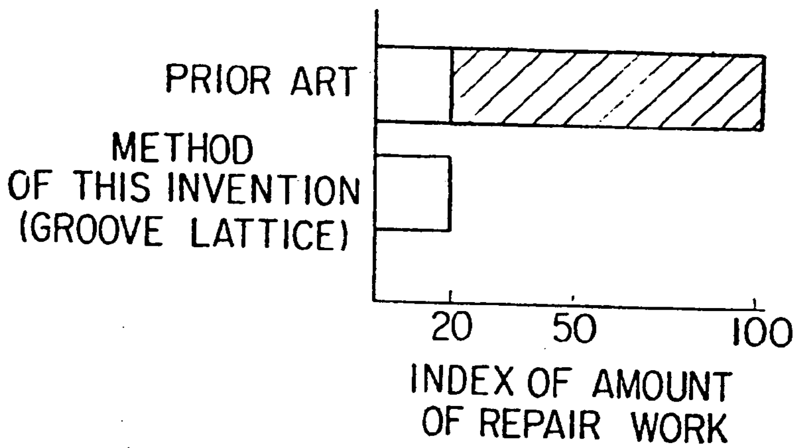


FIG. 4


PRIOR ART
METHOD
OF THIS INVENTION
(GROOVE LATTICE)
20
50
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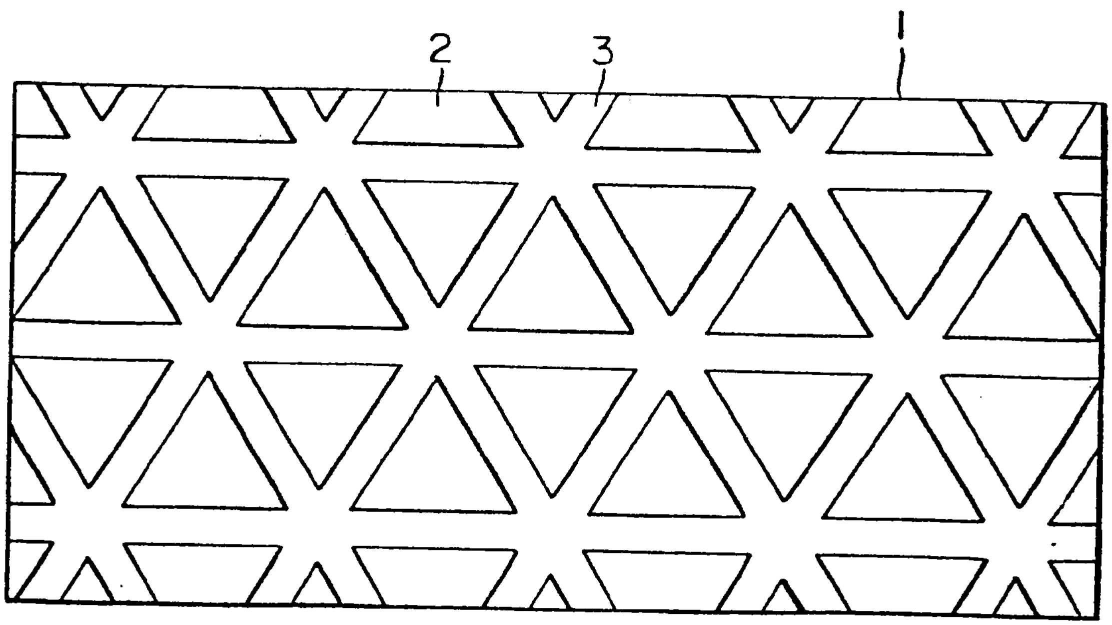
INDEX OF AMOUNT
OF REPAIR WORK

FIG. 5(a)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3
1

FIG. 5(b)

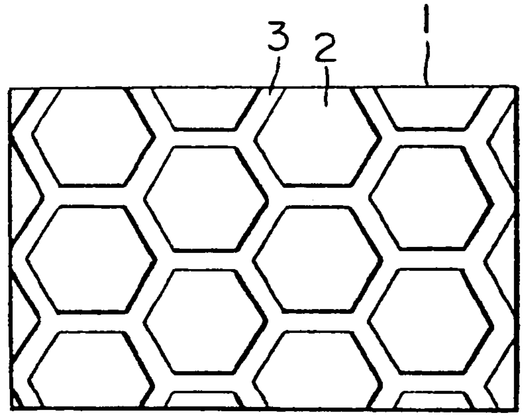



FIG. 5(c)

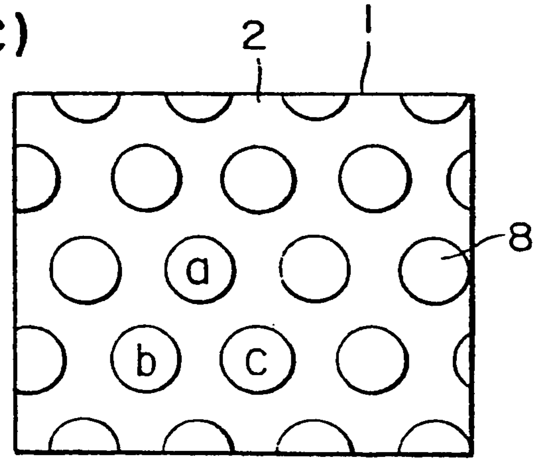



FIG. 5(d)

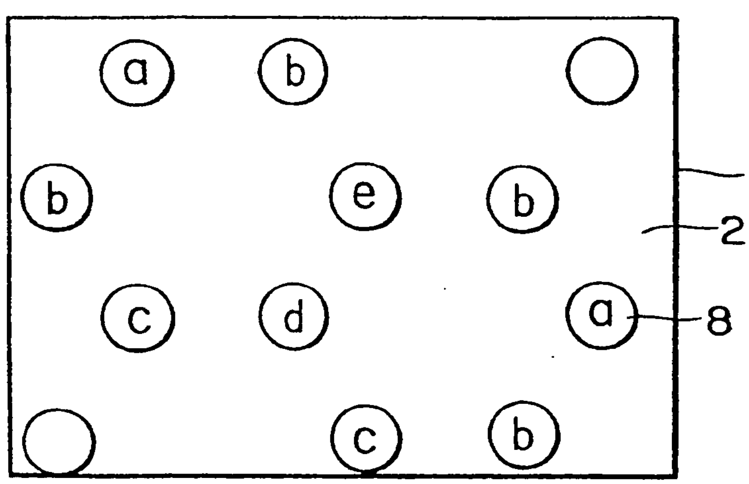


FIG. 6

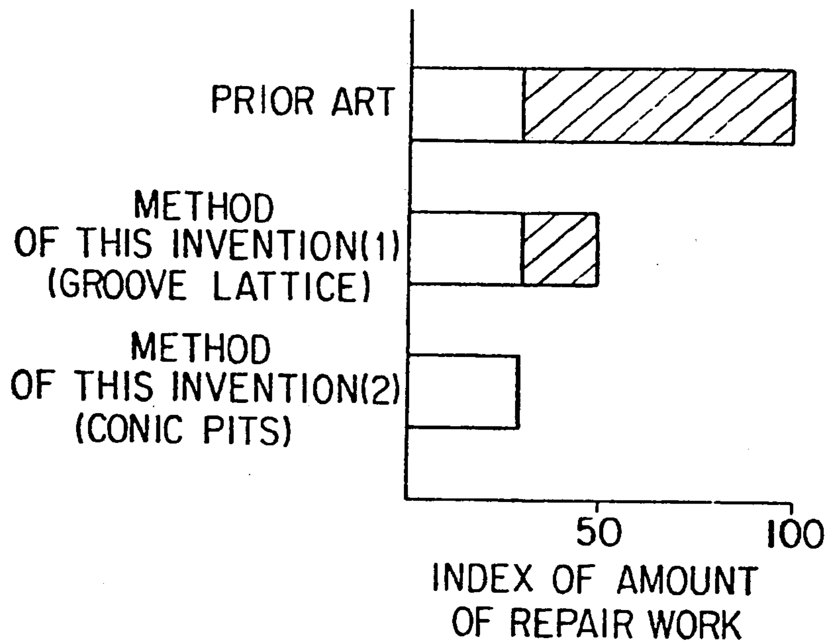



FIG. 7(a)

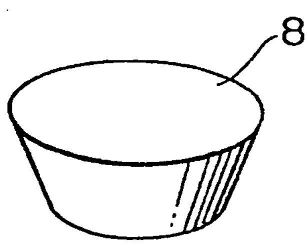



FIG. 7(b)

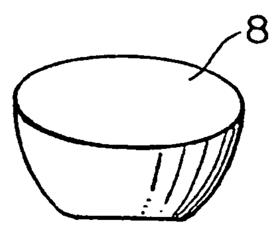


FIG. 8

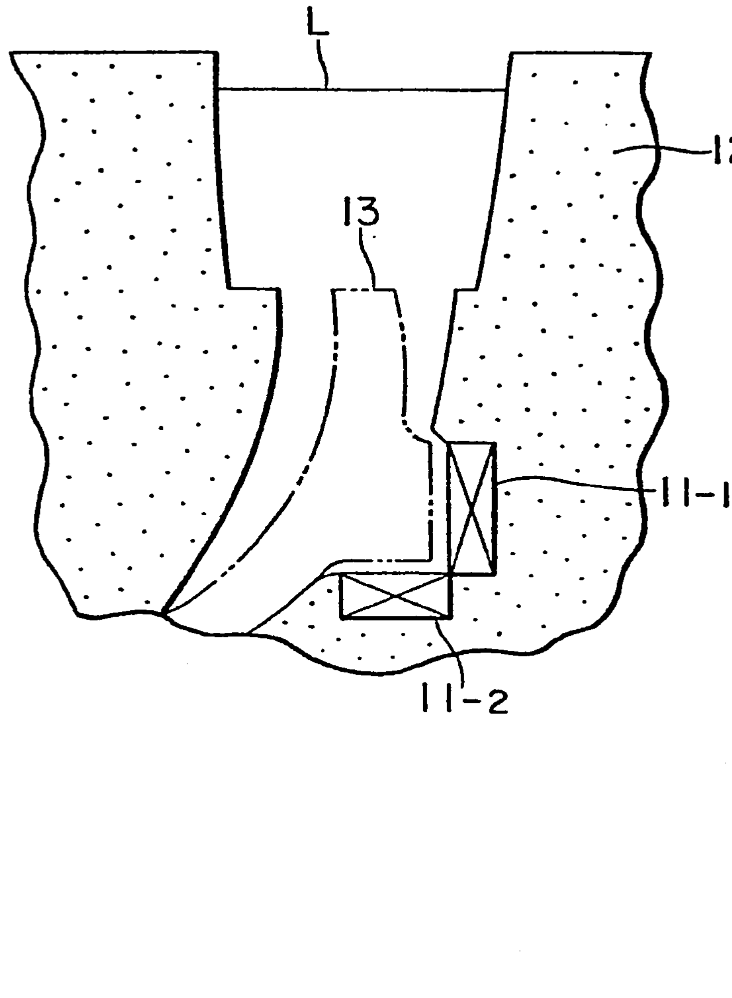


FIG. 9

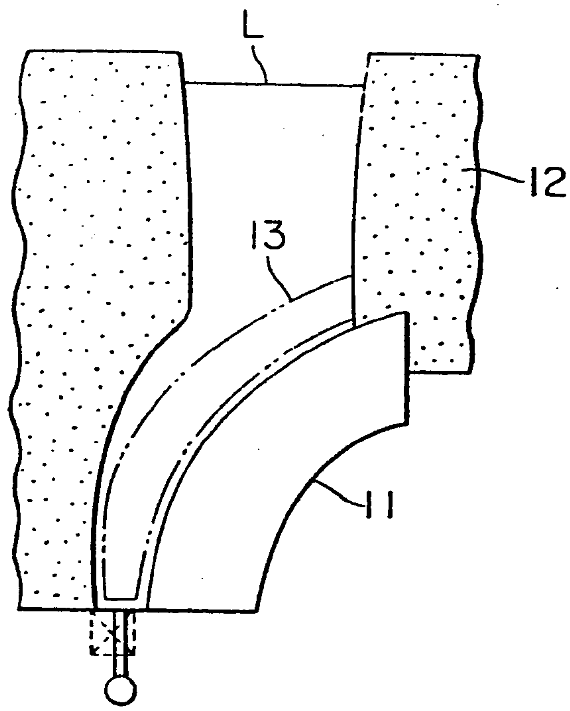
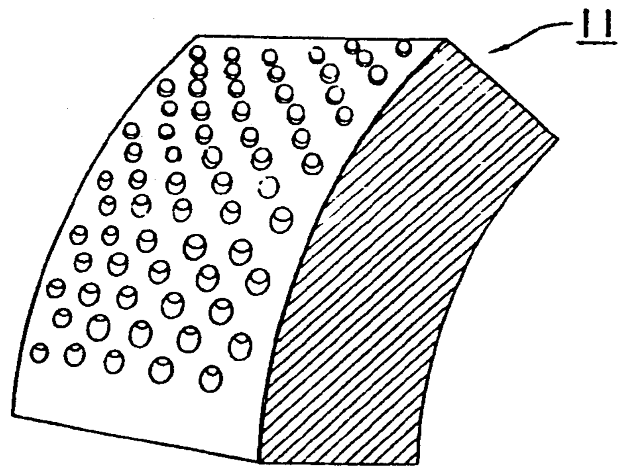



FIG. 10



0094688

European Patent Office

# EUROPEAN SEARCH REPORT

Application number

EP 83 10 4913

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int. Cl. 3) |
|---|---|---|---|
| A | DE-B-2 052 048 (L'ELECTRO-REFRACTAIRE) * Claim 1 * --- | 1 | B 22 D 7/06<br>B 22 D 11/04<br>B 22 D 11/06 |
| A | DE-B-1 906 261 (ZENTRALNY NAUTSCHNO-ISSLEDOWATELSKIJ INSTITUT TSCHERNOJ METALLURGII IMENI I.P. BARDINA) * Claim 1 * --- | 1 | |
| A | EP-A-0 016 905 (ALLIED CHEMICAL CORP.) * Claim 1 * --- | 1 | |
| D,A | US-A-4 250 950 (K. BUXMANN et al.) * Claim 1 * ----- | 1 | |
| | | | TECHNICAL FIELDS SEARCHED (Int. Cl. 3) |
| | | | B 22 D 7/00<br>B 22 D 11/00 |

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| BERLIN | 10-08-1983 | GOLDSCHMIDT G |

CATEGORY OF CITED DOCUMENTS

X particularly relevant if taken alone
Y particularly relevant if combined with another document of the same category
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O non-written disclosure
P intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
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